## REMARKS / ARGUMENTS

With this amendment, no changes have been made to the claims or the specification of this case. Therefore, claims 1-8, 11-18, 28, 30-39, and 42-65 remain pending in this case.

This is a response to the Examiner's May 11, 2004 rejection of claims 1-8, 11-18, 28, 30-39, and 42-65 in which:

- claims 1, 3-5, 28, 33, 34, 39, 54, 56, 58, and 60-63 were rejected under 35 U.S.C. § 103(a) as being unpatentable over Tinkham, *Introduction to Superconductivity*, Second Edition, McGraw-Hill, 1996 (hereinafter "Tinkham"), in view of United States Patent 5,157,466 to Char *et al.* (hereinafter "Char");
- claims 2, 30-32, and 52 were rejected under 35 U.S.C. § 103(a) as being unpatentable over Tinkham in view of Char and further in view of Shnirman *et al.*, Physical Review B 57, p. 15400, 1998 (hereinafter "Shnirman");
- claims 6, 8, 35, 53, 55, 57, 59, 64, and 65 were rejected under 35 U.S.C. § 103(a) as being unpatentable over Tinkham in view of Char and further in view of United States Patent 3,953,749 to Baechtold *et al.* (hereinafter "Baechtold);
- claims 7, 11-18, 36, 37, 42, 43, 45, 46, and 48-50 were rejected under 35 U.S.C. § 103(a) as being unpatentable over Tinkham in view of Char, Baechtold and further in view of Shnirman;
- claims 38, 44, 47, and 51 were also rejected under 35 U.S.C. § 103(a) as being unpatentable over Tinkham in view of Char, Baechtold and further in view of Shnirman; and
- claims 1-8, 11-18, 28, 33-39, and 42-65 were rejected under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1-6, 12, 14, 15, and 18-25 of U.S. Patent No. 6,459,097 in view of Char.

## THE 35 U.S.C. § 103(a) REJECTIONS SHOULD BE WITHDRAWN

Applicants respectfully traverse the 35 U.S.C § 103(a) claim rejections for the reasons discussed below. This reasoning is delineated into the following groups of claims:

Group I: claims 1-8, 11-18, 28, 30-39, 42-59, and 64-65; and
Group II: claims 60-63

Group I: Claims 1, 8, 28, 39, 60, and 64 and each of the claims that depend from these independent claims

In the final office action mailed May 11, 2004, the Examiner rejected claim 1 under 35 U.S.C. § 103(a) as being unpatentable over Tinkham in view of Char. Claim 1 recites (i) a first bank of a superconducting material, (ii) a mesoscopic island of a superconducting material, where at least one of the island and the bank comprises a d-wave superconducting material, and (iii) a clean Josephson junction between the island and the bank. Each of the independent claims (claims 1, 8, 28, 39, 60, and 64) recite at least these three elements in a quantum computing device (*e.g.* a quantum computing structure, a quantum register, or a qubit).

The Examiner asserts that the top paragraph of page 248 of Tinkham shows a small superconducting island connected to charge reservoirs and further, page 256, last full paragraph, shows a small superconducting island connected to two macroscopic superconducting leads. Next, the Examiner points out that column 2, line 3 et seq. and Fig. 14 of Char show the formation of a grain boundary Josephson junction 314 of high temperature superconductor material where an island 310 is connected to a body 312. The Examiner states that it would have been obvious to use the Char structure for the Tinkham device "since it is known to be functional." Although neither Char nor Tinkham teach or suggest a clean Josephson junction, the Examiner states that it would be obvious to provide the best quality crystal structures since this is standard in semiconductor processing.

When rejecting claims under 35 U.S.C. § 103, the PTO bears the burden of establishing a *prima facie* case of obviousness. *In re Bell*, 26 USPQ2d 1529 (Fed. Cir. 1993). To establish a *prima facie* case, the prior art reference, or references when combined, must teach or suggest each and every limitation of the claimed invention. MPEP § 706.02(j). The teaching or suggestion to make the claimed invention and the reasonable expectation of success must both be found in the prior art, not in the Applicant's disclosure. *In re* Vaeck, 20 USPQ2d 1438 (Fed. Cir. 1991). There must be some motivation, suggestion, or teaching of the desirability of making the specific combination that was made by the Applicant. *In re Fine*, 837 F.2d 1071, 1075 (Fed. Cir. 1988).

In the present instance, one relevant inquiry is whether the cited art, either alone or in combination, teaches each and every limitation of the rejected claims. To this end, Applicants submit that the Examiner's rejection of the claims is unfounded because Char and Tinkham, either alone or in combination, do not teach or suggest the clean Josephson junction(s) that are recited in each of the independent claims. Another relevant inquiry is

whether the prior art provides one of ordinary skill in the art with a suggestion or motivation to modify or combine the teachings of the references relied upon by the Examiner to arrive at the claimed invention. As discussed in detail below, the cited art fails to satisfy either of these requirements.

### I. Char does not teach or suggest a clean Josephson junction

Each of the independent claims recites at least one clean Josephson junction. In the May 11, 2004 Office Action, the Examiner stated that the clean Josephson junction limitation in claim 1 does not render the claim patentable over the combination of Char and Tinkham. The Examiner reasoned that it would have been obvious to provide the best quality crystal structures since this is standard in semiconductor processing. Applicants will discuss the current-phase relationship of Josephson junctions made from conventional superconducting materials and unconventional superconducting materials in Section I-A. Then, the current-phase relationship of clean Josephson junctions will be discussed in Section I-B. Then, in subsequent sections, Applicants will discuss why Char and Tinkham do not teach or suggest clean Josephson junctions and why there is no motivation to modify Char to incorporate clean Josephson junctions into Char devices.

### Section I-A: Josephson junction current-phase relationships

In general, the current-phase relation of a Josephson junction is described by an odd periodic function commonly represented by the Fourier expansion:

$$I(\varphi) = I_1 \cdot \sin(\varphi) + I_2 \cdot \sin(2\varphi) + \ldots, \qquad (1)$$

where $I_1$ and $I_2$ represent the critical current of the first and second harmonics respectively. In Josephson junctions formed out of conventional superconducting materials, the second harmonic term and higher terms are negligible. See Il'ichev *et al.*, 1999, Physical Review B 60, p. 3096, (hereinafter "Il'ichev 1999"), second column ("The $I_2$ term is also present in weak links based on conventional *s*-wave superconductors but for all known types of weak links $|I_2 / I_1| < 1$. For instance, for a tunnel junction $|I_2 / I_1| << 1$").

The order parameter of a superconducting material determines the properties and characteristics of the superconducting material, and hence the current-phase relationship of weak links formed in the material. Conventional superconducting materials have isotropic

order parameters. In contrast, unconventional superconducting materials have anisotropic order parameters. A common unconventional superconducting material is the d-wave superconductor $YBa_2Cu_3O_7$-x (YBCO), which is used in both Char and Il'ichev 1999. The term "d-wave" indicates the type of symmetry of the anisotropic order parameter.

Due to the anisotropy of the d-wave order parameter, the current-phase relationship for a Josephson junction in a d-wave superconductor has the potential of having a temperature dependent second harmonic term. The current-phase relationship of the Josephson junctions described in Il'ichev 1999 is:

$$I_P = I_c^I \cdot \sin(\varphi) + I_c^{II} \cdot \sin(2\varphi), \tag{2}$$

where $I_c^I$ and $I_c^{II}$ are the critical currents of the first and second harmonics respectively. Il'ichev 1999 established that the realized non-sinusoidal behavior in the current-phase relationship of this clean Josephson junction is explained by the presence, and in some cases dominance, of the second harmonic term. See, for example, Fig. 4 of Il'ichev 1999, where the second order harmonic $I_2$ dominates over the first order harmonic $I_1$ at lower temperatures.

<u>Section I-B: Clean Josephson junctions</u>

The greater the influence of the second harmonic in the current-phase relationship of a Josephson junction, the greater the deviation from conventional $2\pi$ periodic sinusoidal behavior. A clean Josephson junction is defined by a current-phase relationship in which the second harmonic makes a distinct contribution to the characteristics of the junction. (See point 5 of the declaration of Dr. Alexander Tzalenchuk under 37 C.F.R. § 1.132 submitted in response to the February 19, 2003 Office Action on April 18, 2003, attached hereto as Exhibit A). In terms of Eqn. 2, this is the regime where $I_c^{II} > I_c^I / 2$, which causes the equilibrium state to shift from $\varphi=0$, in the sinusoidal case, to about $\pm\pi/2$, creating a double degenerate ground state phase difference across the junction. In other words, the phase differences of about $+\pi/2$ and $-\pi/2$ have equal energy across the unconventional superconductor clean Josephson junction.

The double degenerate ground state associated with a clean Josephson junction is used in the present invention in order to cause persistent supercurrents that spontaneously arise in the claimed devices to have two degenerate ground states. See page 9, lines 6-28, of Applicants' specification. As discussed in I-A, such persistent supercurrents arise spontaneously in the vicinity of the clean Josephson junction when at least one of bank 110 and island 120 (Applicants' Fig. 1A) is made of a d-wave superconducting material. As discussed in Il'ichev 1999, page 3098, first column, and as depicted in Fig. 4 of Il'ichev 1999 (Exhibit B), the size of the second harmonic is dependent on temperature. It can be suppressed by raising the temperature of the junction. When the second harmonic is suppressed, the junction behaves as a conventional Josephson junction.

<u>Section I-C: Char</u>

Char does not teach or suggest clean Josephson junctions. The current-phase relationship of a Josephson junction comprised of a conventional superconducting material has a sinusoidal dependence. See Il'ichev, 1998, Physical Review Letters 81, p. 894, first column, "[t]his sinusoidal dependence has been confirmed experimentally numerous times for standard tunnel junctions between conventional superconductors"). Il'ichev 1998 is attached hereto as Exhibit C. Il'ichev 1998 describes the fabrication of clean Josephson junctions in unconventional superconductors and measurement of their current-phase relationship. Il'ichev 1998 predicted and found significant deviations from the sinusoidal dependence that is typical of conventional Josephson junctions (See Il'ichev 1998, p. 896, first column, "strong deviations from the standard sinusoidal dependence have been predicted for the current-phase relations of various configurations of Josephson junctions employing such unconventional superconductors"). Il'ichev 1999 (Exhibit B) found that the deviations from the sinusoidal dependence were temperature dependent (Il'ichev, page 3098, column 1, "the amplitude of the $\pi$-periodic component of the CPR decreases drastically with increasing temperature").

A review of Fig. 15 of Char is instructive. As illustrated in Fig. 15 of Char, the voltage phase properties of the Char devices illustrate temperature independent conventional sinusoidal behavior, indicating that the second harmonic is suppressed at *all* temperatures in complete contrast to the teachings of Il'ichev 1999 (Exhibit B, p. 3098 column 1, first full paragraph). In other words, Fig. 15 of Char shows that the Char devices "operate properly" (*i.e.*, exhibits $2\pi$ periodic sinusoidal behavior) at temperatures ranging from 4.2K to 77K (see Char, column 15, lines 35-40). This indicates that the Josephson junctions of Char are not in

the clean regime. If the Char devices were in the clean regime, then the voltage phase relationship of a Char device would adopt a sinusoidal waveform at high temperatures (68K) and a non-sinusoidal waveform at low temperatures (4.2K). Fig. 3 of Il'ichev 1999 (p. 3098) shows such a temperature dependence. In Fig. 3 of Il'ichev 1999 (Exhibit B), the non-sinusoidal behavior of a Josephson junction capable of exhibiting second harmonic effects is lost as the temperature of the junction is shifted from 4.2K to 40K. Thus, Char describes Josephson junctions for which the second harmonic is suppressed between 4.2K and 77K. This means that Char does not teach or suggest clean Josephson junctions.

<u>Section I-D: Tinkham does not teach or suggest a clean Josephson junction</u>

Tinkham does not remedy the deficiencies of Char. In particular, Tinkham does not teach or suggest a clean Josephson junction. As noted by the Examiner on page 2 of the May 11, 2003 office action, Tinkham does not detail the materials of the island, leads to the island or Josephson junctions.

<u>II. There is no motivation in the art to modify Char so that it would have a clean Josephson junction</u>

In the May 11, 2004 Office Action, the Examiner stated that it would have been obvious to provide the best quality crystal structures since this is the standard in semiconductor processing. Applicants respectfully submit that the practice of providing the best quality crystal structures would not have resulted in the modification of Char or Tinkham to include clean Josephson junctions at the time the present application was filed for two reasons. First, the Char devices were constructed using biepitaxial technology. Even the best biepitaxial technology available at the time the present application was filed could not have achieved the unconventional superconductor clean Josephson junctions recited in the pending claims. Second, even if it were possible to modify Char to make the claimed junctions, such junctions would have electrical characteristics that are undesirable for the conventional devices proposed by Char. Because of these undesirable electrical characteristics, their use in the conventional electronic devices described in Char would result in unsatisfactory device performance. This reasoning is outlined in the following subsections.

Section II-A: Neither Char nor the best quality crystal structures available for biepitaxial Josephson junction technology at the time of filing of the application were sufficiently advanced to make a clean Josephson junction.

In order to produce a Josephson junction in a d-wave superconducting material such as $YBa_2Cu_3O_7$-x (YBCO), the two sides of the junction must have different crystallographic orientation. There are three general approaches to fabricating such junctions, bicrystal, biepitaxial, and step-edge. See page 1, middle of column 2, of Tafuri *et al.*, cond-mat/0010128, Oct. 9, 2000, attached hereto as Exhibit E "YBCO GB junctions are usually classified as bicrystals, biepitaxials, and step-edges, depending on the fabrication procedure." While not intending to be limited to any particular fabrication technique, Applicants disclose a bicrystal fabrication technique on page 8, lines 3-18, of the specification. In Applicants' bicrystal fabrication technique, the substrate itself is a bicrystal substrate, such as a strontium-titanate bicrystal. When a d-wave superconductor such as YBCO is grown or deposited on the bicrystal substrate, it produces two banks having different orientations. On page 8 of the specification, Applicants cite and incorporate by reference Il'ichev *et al.*, 1998 cond-mat/9811017, which is attached hereto as Exhibit F. Page 2, bridging paragraph between columns 1 and 2 of Il'ichev 1998, disclose more details of the bicrystal fabrication technique. Further, the reference demonstrates the successful use of the fabrication technique to make clean Josephson junctions in YBCO. As noted by Tafuri *et al.*, bicrystal techniques typically offer junctions with better performances than biepitaxials (Tafuri, Exhibit E, page 1, second column, "[t]he bicrystal technique typically offers junctions with better performances").

Char uses a biepitaxial technique to form Josephson junctions. In the Char biepitaxial approach, a seed layer is introduced onto a portion of the substrate. See, for example, element 42 in Figs. 3-10 of Char. When YBCO is grown or deposited on a substrate that includes the seed layer, the YBCO overlying the seed layer adopts a different orientation than the portion of the substrate that does not overlay the seed layer. The boundary, therefore, between the YBCO overlying the seed layer and the YBCO overlying the native substrate forms a Josephson junction. See, for example, Fig. 3 of Char, including the Josephson junction (element 30).

Biepitaxial grain boundary Josephson junction technology was not sufficiently advanced at the time of filing of the instant Application to form clean Josephson junctions. This is evidenced by Tafuri (Exhibit E). Tafuri provides new experimental procedures to

produce biepitaxial YBCO Josephson junctions. On page 1 of Tafuri, it is noted that these experimental techniques could *possibly* be used to obtain a Josephson junction that has a double degenerate state [*i.e.*, a clean Josephson junction, "[i]n this paper we discuss how $YBa_2Cu_3O_{7-x}$ (YBCO) structures made by the biepitaxial technique can be successfully employed to produce arbitrary circuit geometries in which both "0" and $\pi$-loops are present, and possibly to obtain a doubly degenerate state"]. Further, it is noted that the biepitaxial techniques of Tafuri represent significant improvements over the biepitaxial techniques of Char (Tafuri, page 1, second column, referencing Char *et al.*, 1991, Applied Physics Letters 59, p. 733, attached hereto as Exhibit G, "we intend to show that significant improvements with respect to the original technique developed by Char et al. are possible for biepitaxial junctions, and that the resulting devices have potential for applications"). The Char *et al.* reference cited by Tafuri is the same biepitaxial technology that is disclosed in United States Patent 5,157,466 to Char. Compare, for example, the text beginning on the second full paragraph on p. 733, column 2 of Char, Applied Physics Letters 59, to column 9, lines 49-64 of United States Patent 5,157, 466. Also, compare Figs. 2, 3, and 4 of Char, Applied Physics Letters 59 to Figs. 13, 14, and 15 of United States Patent 5,157, 466. Clearly, when Tafuri was published, more than ten months after the time of filing Applicants' application, biepitaxial techniques that *might* produce double degenerate (clean) Josephson junctions in YBCO were only first being proposed. Given the difficulties with biepitaxial technology at the time the present application was filed, one of ordinary skill in the art would not have been able to modify Char to produce the devices claimed in the instant application. As such, the combination of Char and Tinkham does not provide a motivation to modify such references in order to make the claimed devices.

Section II-B: Unpredictability of the second harmonic in clean Josephson junctions

Even if biepitaxial technology could be used to make a clean Josephson junction, the prior art does not provide a fair motivation to make such junctions. As discussed above, the current-phase relationship of a clean Josephson junction is nonsinusoidal, due to contributions from the second harmonic term, whereas a conventional Josephson junction is sinusoidal, due to the dominance of a first harmonic term and the suppression of a second harmonic term. Further, at least in the case of a YBCO thin film with asymmetric 45 degree [001]-tilt grain boundaries, the contribution from the second harmonic term in clean Josephson junctions is temperature dependent. Thus, the use of clean Josephson junctions in the devices of Char would introduce an unpredictable temperature dependence on the current-

phase dependence in such devices. Since the devices of Char are typically used in applications such as the precise measurement of magnetic fields (Char, column 2, lines 15-17, "[w]eak-link junctions make it possible to create extremely sensitive instruments to measure magnetic field, voltage, and current"), this unpredictable current-phase dependence is undesirable.

The unpredictability in the current-phase relationship of clean Josephson junctions, comes from at least two sources. First, as discussed above and as illustrated in Il'ichev 1999 (Exhibit B, e.g., Figs. 3 and 4), the second harmonic contribution associated with a clean Josephson junction is temperature dependent. Second, as detailed in Il'ichev 1999 and in Lindström, state of the art methods for manufacturing clean Josephson junctions still have not developed to the point where the strength of the second harmonic can be precisely engineered. In Il'ichev 1999, six bicrystal YBCO Josephson junctions were fabricated and studied. Of the six samples, only four produced clean Josephson junctions (Il'ichev 1999, page 3097, column 2, "[w]e have studied six samples, out of which for four samples the $\pi$-periodic component $I(\varphi)$ was experimentally observed"). Furthermore the second harmonic contribution of each of the six samples was different (See Il'ichev 1999, column 2, page 3097). Lindström fabricated a number of devices that include Josephson junctions in YBCO using bicrystal techniques. Lindström reported that the critical current varied from sample to sample (Lindström, Exhibit D, page 117002-2, column 2, third full paragraph). Further, Lindström found that the first order and second order harmonics varied by as much as ten times between the two junctions in each of the manufactured devices. (Lindström, page 117002-4, column 1, first paragraph "[t]he ratios of $I_c^I$ and $I_c^{II}$ can vary as much as 10 times between two junctions in the same SQUID"). Thus, even the state of the art methods for manufacturing clean Josephson junctions such as Il'ichev 1999 and Lindström have failed to make clean Josephson junctions with consistent second order harmonics.

The results of Il'ichev 1999 and Lindström show that each clean Josephson junction would have to be characterized to determine the magnitude of the first and second harmonics. Such a step is not presently needed in Char and there is simply no motivation to alter Char to introduce such a step since Char does not teach or suggest the use of devices that make use of the second order harmonics of clean Josephson junctions. In contrast, characterization of each clean Josephson junction for use in the quantum devices claimed by Applicant provides no drawback.

Section III-C: The prior art provides no motivation to combine Tinkham and Char

If it is not shown that the prior art gives a reason or motivation to make the claimed invention, then there is no *prima facie* case and the Applicant should prevail. *In re Grabiak*, 769 F.2d 729 (Fed Cir 1985). It is improper to use hindsight reconstruction based upon the disclosure of the Applicant's own specification. These type of hindsight rejections are specifically prohibited. See *In re Vaeck*, 947 F.2d 488, 493, 20 U.S.P.Q.2d 1438, 1442 (Fed. Cir. 1991); and *In re Fine*, 837 F.2d 1071, 1075, 5 U.S.P.Q.2d 1596 (Fed. Cir. 1988).

Even if Char were combined with Tinkham, the present invention would not be obvious since neither of them teaches the specific claimed structures as explained above. In addition, there is nothing in the references to motivate one of ordinary skill in the art to modify the structures disclosed in the cited references to arrive at the claimed invention. The Applicant's own disclosure cannot be used to fill the gap between the cited references and the claimed invention.

Summary

For the above-identified reasons, claims 1, 8, 28, 39, 60, and 64 are patentable over any combination of Tinkham and Char. Furthermore, all other pending claims depend from one of these claims and are therefore patentable over the combination of Tinkham and Char for at least the same reasons. Certain claims are rejected as being unpatentable over Tinkham, in view of Char and further in view of Baechtold. However, Baechtold merely teaches a binary circuit consisting of a series/parallel arrangement of Josephson junctions. As such, Baechtold does not remedy the above-identified deficiencies in the combination of Tinkham and Char. Certain of the claims are rejected as being unpatentable over Tinkham, in view of Char, in view of Shnirman. However, Shnirman merely teaches a single-electron transistor capacitively coupled to a Josephson junction qubit. As such, Shnirman does not remedy the above-identified deficiencies in the combination of Tinkham and Char. Certain of the claims are rejected as being unpatentable over Tinkham, in view of Char, Baechtold, and further in view of Shnirman. None of these references, either alone or in combination, remedy the above-identified deficiencies. For these reasons, all the claims are patentable over any combination of Tinkham, Char, Baechtold, and Shnirman. Additional reasons for patentability of some of the pending claims are provided in the following subsection.

## Group II: Claims 60-63

Claims 60-63 are directed to a qubit with circuitry to allow selective interruption of quantum tunneling between a first ground state and a second ground state. In the May 11, 2004, Office Action, the Examiner stated that claims 60-63 are unpatentable over Tinkham in view of Char because Char shows a superconducting quantum interference device (SQUID) and the Examiner argued that tunneling occurs in such devices. While tunneling may in fact occur in such devices, it is not quantum tunneling as claimed in claims 60-63. Quantum tunneling can only arise in a mesoscopic system. Char does not teach or suggest a SQUID that is mesoscopic. Tinkham teaches a mesoscopic island but does not teach or suggest a SQUID. Furthermore, there is no suggestion in either reference nor any motivation in the art to combine the two references to make a mesoscopic SQUID.

## The rejection of the pending claims under the judicially created doctrine of obviousness-type double patenting.

In the May 11, 2004 Office Action, the Examiner provisionally rejected claims 1-8, 11-18, 28, 33-39, and 42-65 under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1-6, 12, 14, 15, and 18-25 of U.S. Patent No. 6,459,097 in view of Char. This rejection reflects that claims 9, 10, 29, 40, and 41, have been canceled. A Terminal Disclaimer in compliance with 37 CFR 1.321 is submitted herewith. Reversal of the double patenting rejection is therefore respectfully requested.

## CONCLUSION

For all of the foregoing reasons, reversal of the rejections of claims 1-8, 11-18, 28, 30-39, and 42-65 is respectfully requested. Applicants respectfully request that the above-mentioned amendments and remarks be entered and made of record in the file history of the subject application.

It is believed that no fees are due in connection with the filing of this amendment. However, should the Patent Office determine otherwise, please charge the required fee to Jones Day deposit account no. 50-3013, referencing CAM No. 706700-999101.

Respectfully submitted,

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